The Hydrogen Spectrum & Energy Levels
Spring 2025

Introduction

In this experiment you will use a diffraction grating to measure the wavelengths of three visible lines emitted by hydrogen, and from those results determine the allowed energy levels of the hydrogen electron (*Note that a fourth line is produced in the hydrogen spectrum at visible wavelengths, but you won't be able to see it during today's experiment*). You should be able to measure the wavelength of each line to within 1 or 2%!

Experiment

1. *Measuring the diffraction angle for Hydrogen and Sodium lines:*

a. Your instructor will explain the operation and initial setup of the spectrometer, as shown in **Figure 1**.

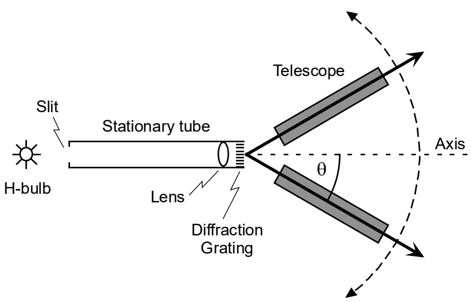

Figure 1: The spectrometer

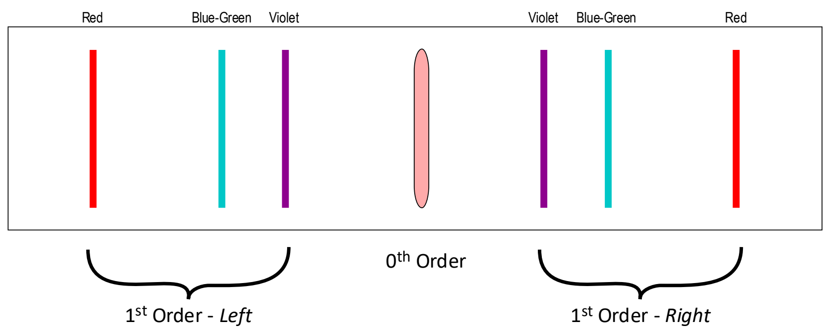

Figure 2: The view of hydrogen spectral lines through spectrometer eyepiece

b. Your lab instructor has taken pity on you this week and has added the following data table to the lab journal template you have downloaded:

Line Color	θ_{left} (°)	θ_{right} (°)	$<\theta>$ (°)	λ (nm)
Violet				
Blue-Green				
Red				
Yellow *(in Sodium)*				**589.3**

c. When the room lights have been turned off, look through the telescope, which should be in a straight line with the stationary tube facing the hydrogen bulb. At the center you will see a pink line; this is the 0^{th} order image of the hydrogen bulb (**Figure 2**).

d. Move the telescope by pushing on the pointer. Swing the telescope *left* of center until the crosshair is lined up with the first hydrogen line you see (the violet line in **Figure 2**). When this line is centered, record θ_{left}, the angle indicated by the pointer (<u>you should estimate angles to 0.1°</u>). Have your partner check the angle as well.

e. Continue moving the telescope to the left to record the angle for the blue-green and red lines.

f. Move the telescope so that it is again lined up directly with the stationary tube. Now swing the telescope *right* of center and repeat the measurements of θ_{right} for the three hydrogen lines visible from the right side.

g. Calculate $<\theta>$, the average for each hydrogen line observed.

h. Now you are ready to determine the relationship between your measured angle and the wavelength. <u>*Carefully*</u> carry your spectrometer to one of the sodium bulbs and place it on the platform. *Your instructor will help you align it properly*.

i. Measure the angle θ of the yellow line that appears to the left and right of center. *Don't measure the* ***bright*** *yellow, 0th order image of the sodium bulb when the spectrometer is pointing directly at the sodium bulb!*

2. *Calculating wavelengths:*

We will use *Eqn. 1* to calculate λ, the wavelength of each spectral line observed in hydrogen. Recall that ***m*** is the order of the image, ***d*** is the grating spacing and **θ** is the measured angle (*use* `SIN(RADIANS(θ))` *in Excel*):

$$m\lambda = d\sin\theta \qquad (Eqn.\ 1)$$

a. First, we need to calculate the value of the grating spacing. Solve *Eqn. 1* for ***d*** using the wavelength of the yellow line of sodium (λ_{Na} = 589.3 *nm*) and your measured angle for the sodium line (what is the value of ***m*** here?) Calculate ***d*** to one-tenth of one *nanometer*. Check with your instructor that you have a reasonable value for ***d***.

b. Now use your calculated value of ***d*** and *Eqn. 1* to calculate the wavelength of each hydrogen line observed. **Be sure to calculate your wavelengths to 0.1 *nm* (4 significant figures)!**

3. *Calculating theoretical energy levels and wavelengths:*

a. The last sheet of this week's lab journal template contains a large energy level diagram (**Figure 3**), along with a second data table. In this table, first calculate the theoretical energy levels (*units: eV*) for n = 1 through n = 6 using *Eqn. 2*:

$$E_n = \frac{-13.61}{n^2} \qquad (Eqn.\ 2)$$

Note that the energy of each level automatically appears on the right side of ***Figure 3*** *in your journal.*

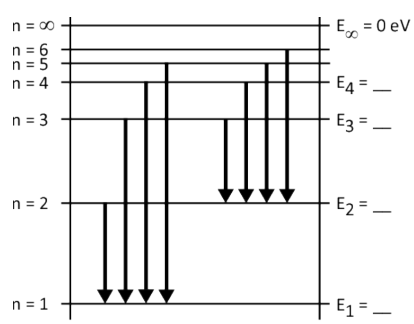

Figure 3: The energy level diagram for hydrogen. Each *transition* of an electron from a higher to lower energy level – resulting in the emission of a photon – is represented by an arrow. Two *series* of transitions are shown, with one series ending at energy level n = 1 and the other at n = 2. Note that energy levels 1 through 6 are the only ones shown, but there are an infinite number of levels.

b. Use *Eqn. 3* to calculate $\lambda_{n=1}$ and $\lambda_{n=2}$, the wavelengths of *all eight* transitions ending at the n = 1 and n = 2 energy levels in **Figure 3**, respectively. Note that λ has units of *nm* when ΔE is in *eV*:

$$\lambda = \frac{1240\,\{eV \cdot nm\}}{\Delta E} = \frac{1240}{E_{Upper\ Level} - E_{Lower\ Level}} \qquad (Eqn.\ 3)$$

Excel note: Use an *absolute cell reference* for the energy of the lower level in your equation by adding dollar signs to the cell address. For example, if the energy of the lower level is in cell **O3**, use `$O$3` in your equation. When the equation is copied, it will always refer to this cell. *Pro tip*: When creating the equation, click on cell **O3** and press function key **F4** once (Macintosh: press and hold the **fn** key and then press the **F4** key) to add the dollar signs.

4. *Identify the transitions from your measured colors:*

a. Identify the series and the individual transitions in the energy level diagram for each line observed by comparing your measured wavelengths with those found in step (3b) above.

b. Change the color of the transition arrows on the energy level diagram to match the spectral lines you observed (violet, blue-green, and red) as follows:

   i. Select a transition arrow and then click the *Shape Format* menu.

   ii. Click *Shape Outline* and then choose the appropriate color from the drop-down menu (the *Shape Outline* icon appears on small screens as shown in **Figure 4**).

Figure 4: The *Shape Outline* icon

c. Finally, calculate the percent difference between your measured and calculated values of the wavelength for each line.

d. Try not to shed a tear as you quietly exit the physics lab for the last time.

Please Turn Off the Flashlight and Hydrogen Bulb When Finished!

Good Luck on Your Finals and Have a Great Summer!